

## Improvement of the performance of STATCOM in terms of voltage profile using ANN controller

**Mohammed Salheen Alatshan<sup>1</sup>, Ibrahim AlHamrouni<sup>2</sup>, Tole Sutikno<sup>3</sup>, Awang Jusoh<sup>4</sup>**

<sup>1,2</sup> Electrical Engineering Section, University Kuala Lumpur (UniKL BMI), Gombak 53100, Malaysia

<sup>3</sup> Department of Electrical Engineering, Universitas Ahmad Dahlan, Yogyakarta, Indonesia

<sup>4</sup> School of Electrical Engineering, Universiti Teknologi Malaysia, 81300 Skudai, Malaysia

---

### Article Info

#### Article history:

Received Feb 10, 2020

Revised May 2, 2020

Accepted May 19, 2020

---

#### Keywords:

ANN controller

IEEE 14 bus system

MATLAB/Simulink

PI controller

SPWM

STATCOM

---

### ABSTRACT

The electronic equipments are extremely sensitive to variation in electric supply. The increasing of a nonlinear system with several interconnected unpredicted and non-linear loads are causing some problems to the power system. The major problem facing the power system is power quality, controlling of reactive power and voltage drop. A static synchronous compensator (STATCOM) is an important device commonly used for compensation purposes, it can provide reactive support to a bus to compensate voltage level. In this paper, the Artificial Neural Network (ANN) controlled STATCOM has been designed to replace the conventional PI controller to enhance the STATCOM performance. The ANN controller is proposed due to its simple structure, adaptability, robustness, considering the power grid non-linearities. The ANN is trained offline using data from the PI controller. The performance of STATCOM with case of Load increasing and three-phase faults case was analyzed using MATLAB/Simulink software on the IEEE 14-bus system. The comprehensive result of the PI and ANN controllers has demonstrated the effectiveness of the proposed ANN controller in enhancing the STATCOM performance for Voltage profile at different operating conditions. Furthermore, it has produced better results than the conventional PI controller.

*This is an open access article under the [CC BY-SA](#) license.*



---

### Corresponding Author:

Ibrahim Mohamed Al Hamrouni,  
Electrical Engineering Section,  
Universiti Kuala Lumpur-British Malaysian Institute,  
Batu 8, Jalan Sungai Pusu, 53100, Gombak, Selangor, Malaysia.  
Email: ibrahim.mohamed@unikl.edu.my

---

### 1. INTRODUCTION

The electric power system is a highly nonlinear system that operates in a constantly changing environment; loads, generator outputs, and key operating parameters change continually [1]. The stability depends on the nature of the disturbance that may subject to the system, where the disturbance may occur for a long or short period [2]. There could be damages to the machines connected to the system, cause heating in the electrical equipment, and malfunction of the sensitive equipment. Small disturbances in the form of load changes occur continually, and the system adjusts to the changing conditions. The system must be able to operate satisfactorily under these conditions and successfully meet the load demand. It must also be able to survive numerous disturbances of a severe nature, such as a short-circuit on a transmission line or loss of a large generator [3]. In the past, traditionally it has been used fixed or mechanically switched shunt and series capacitors, reactors and synchronous generators to solve many of these problems. However, there are limitations to the use of these conventional compensators. required performance was not being able to

achieve effectively. Wear and tear in the mechanical components and slow response were the major of the problems [4]. With the rapid increase in power electronics deployment, there was greater need for the alternative technology made of solid-state devices with fast response characteristics.

Recently, flexible AC transmission systems (FACTS) controllers have been mainly used for solving various steady-state control problems and enhance power system stability in addition to their main function of power flow control. Employment of FACTS devices in power systems leads to better performance of the system, for instance, voltage stability, voltage regulation, and power system stability, damping, can be improved by using these devices [5].

A Static Synchronous Compensator (STATCOM) is one of the parallel FACTS devices that is usually used for voltage regulation. It can also be used to improve power system stability by injecting or absorbing reactive power to the network. It is based on a power electronics voltage-source converter (VSC) and if connected to a source of power it can also provide active power [4-6]. The performance of STATCOM is mainly dependent upon how accurately and quickly error signals are compensated, where the best compensation effect can be obtained by proper control of the STATCOM [7]. Conventionally, a STATCOM is controlled by the PI controller, which requires precise linear mathematical models, where are difficult to obtain and fail to perform satisfactorily under parameter variations nonlinearity load disturbance. Thus, the best possible performance from a STATCOM might not be obtained from conventional controllers for different operating points [8, 9].

To avoid the above-mentioned drawbacks. The need was for the development of new controllers with more improved performance [7]. Recently, a major effort has been underway to develop new and unconventional control techniques that can often augment or replace conventional control techniques, ANN techniques have been significantly useful in power electronics for the maintenance of the stability of systems over a wide range of operation. ANN controller can learn, remember and make decisions. Furthermore, it provides a fast dynamic response and their control requires no mathematical model of the system [10, 11]. Several studies have proposed the application of ANN-based control of STATCOM in power system distribution. In this paper, the ANN controller has been designed instead of conventional PI for STATCOM control circuit. Exhaustive simulation studies are carried out for the IEEE 14-bus system to study the performance of designed ANN controller for STATCOM.

## 2. STATIC SYNCHRONOUS COMPENSATOR (STATCOM)

A complete detailed explanation about STATCOM functionality and controllability is as follows:

### 2.1. The basic operating principle of STATCOM

Static Synchronous Compensator (STATCOM) as one of the most important members of the FACTS family, which is increasingly used in modern power systems, is connected in shunt to the system as shown in Figure 1. It is a  $3\emptyset$  voltage system that lets both generation and absorption of reactive power. When system voltage is low, the STATCOM generates reactive power (STATCOM capacitive). When system voltage is high, it absorbs reactive power (STATCOM inductive). It consists of blocks and they are coupling transformer, measurement system, inverter/converter circuit, controller and a dc-link capacitor. The basic operation principle of the STATCOM is based on two AC sources (System and STATCOM) with the same frequency through coupling inductance. The exchange of reactive power between the system and STATCOM is achieved by adjusting the amplitude of the VSC output voltage ( $V_{out}$ ). If the amplitude of the VSC output voltage is greater than the system voltage ( $V_{ac}$ ), the STATCOM generates capacitive reactive power. Otherwise, the STATCOM absorbs inductive reactive power. If the amplitude of the VSC output voltage is equal to the system voltage, the exchange of reactive power between the STATCOM and the system will be zero [8, 10, 12].

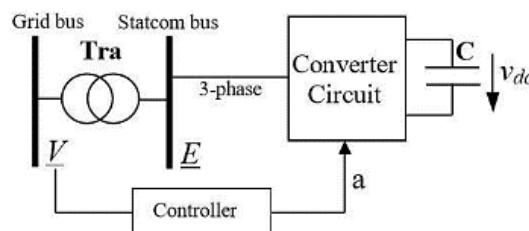


Figure 1. STATCOM in power system

The relation between the fundamental component of the converter ac voltage output and the voltage across the dc capacitor is given as:

$$V_{out} = kV_{dc} \quad (1)$$

Where  $k$  is the coefficient that depends on the number of switching pulses, converter configuration and the converter controls. The fundamental component of the converter voltage output i.e.  $V_{out}$  is dependent on  $V_{dc}$ , can be controlled by varying the dc voltage across the capacitor which can be done by varying the phase angle  $\alpha$  of the converter switching. The direction of reactive power flow either from the system to the coupling transformer or from the coupling transformer to the system is decided by the difference between the converter voltage output and the ac system bus voltage [8].

The reactive power exchanged can be given as follows:

$$Q = \frac{V_{ac}^2 - V_{out}V_{ac} \cos\alpha}{X} \quad (2)$$

The real power exchange between the voltage source converter and the ac system can be given as:

$$P = \frac{V_{ac}V_{out}}{X} \sin \alpha \quad (3)$$

Where:

$V_{out}$  - converter output voltage,

$V_{ac}$  - ac system voltage magnitude,

$X$  - leakage reactance of the coupling transformer.

$\alpha$  - phase angle between the converter output voltage and the system voltage.

## 2.2. Sinusoidal pulse width modulation (SPWM) technique

The most common PWM approach is sinusoidal PWM. In this method, a triangular wave is compared to a sinusoidal wave of the desired frequency and the relative level of the two waves is used to control the switching of devices in each phase leg of the inverter.

The inverter output voltage has the following features.

- 1- SPWM frequency is the same as the frequency of V tri.
- 2- Amplitude is controlled by the peak value of V Control.
- 3- Fundamental frequency is controlled by the frequency of V Control.

The aim of the controller and sinusoidal PWM scheme is to maintain constant voltage magnitude at the point where a sensitive load is connected, under system disturbances. The control system only measures the RMS voltage at the load point, i.e., no reactive power measurements are required. The VSC switching strategy is based on a sinusoidal PWM technique which offers simplicity and good response. SPWM methods offer a more flexible option than the fundamental frequency switching methods favoured in FACTS application.

## 2.3. Voltage source converter (VSC)

VSC is a power electronic tool able of generating a sinusoidal voltage of required frequency, magnitude and phase angle. It converts the d.c voltage through the storage capacitor into three-phase a.c output voltages. The voltages are in phase and coupled with the a.c system through the coupling transformer [13]. The major function of VSC as an integral part of STATCOM is to contribute in mitigating power quality disturbances by injecting or absorbing the required voltage. The required voltage in this case is the difference between reference and actual voltage. The VSC is usually based on some type of energy storage that will supply the d.c voltage. The required voltage can then be getting by switching the solid-state electronic devices in the converter [14].

## 2.4. Structure of STATCOM control circuit

The main function of the STATCOM control circuit is to independently control the active and reactive power supplied to the power system to regulate the voltage generated over the dc-link capacitor. Figure 3 depicts the basic control strategy employed for the STATCOM.

The control system consists of: The Phase-Locked Loop (PLL), measurement systems, abc-dq0 transformation, PI controller, current regulator and the pulse generator.

A phase-locked loop (PLL) which synchronizes on the positive-sequence component of the three-phase primary voltage  $V_1$ . The output of the PLL (angle  $\theta=\omega t$ ) is used to compute the direct-axis and quadrature-axis components of the AC three-phase voltage and currents (labeled as  $V_d$ ,  $V_q$  or  $I_d$ ,  $I_q$  on the

diagram). Measurement systems that measure the d and q components of AC positive-sequence voltage and currents to be controlled as well as the DC voltage  $V_{dc}$ . An outer control loop consisting of a PI controller for AC voltage and another PI controller for DC voltage. The output of the PI controller for AC voltage is the reference current  $I_{qref}$  for the current regulator ( $I_q$  = current in quadrature with a voltage which controls reactive power flow). The output of the PI controller for the DC voltage is the reference current  $I_{dref}$  for the current regulator ( $I_d$  = current in phase with a voltage which controls active power flow). An inner current regulation loop consisting of a current regulator. The current regulator controls the magnitude and phase of the voltage generated by the SPWM converter ( $V_{2d}$ ,  $V_{2q}$ ) from the  $I_{dref}$  and  $I_{qref}$  reference currents produced respectively by the PI controller for AC voltage and the PI controller for the DC voltage (in voltage control mode). The current regulator is assisted by a feed-forward type regulator which predicts the  $V_2$  voltage output ( $V_{2d}$ ,  $V_{2q}$ ) from the  $V_1$  measurement ( $V_{1d}$ ,  $V_{1q}$ ) [15].

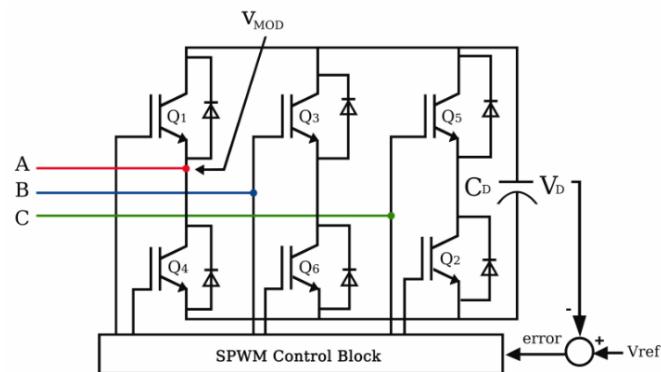


Figure 2.VSC using IGBT-based SPWM inverters

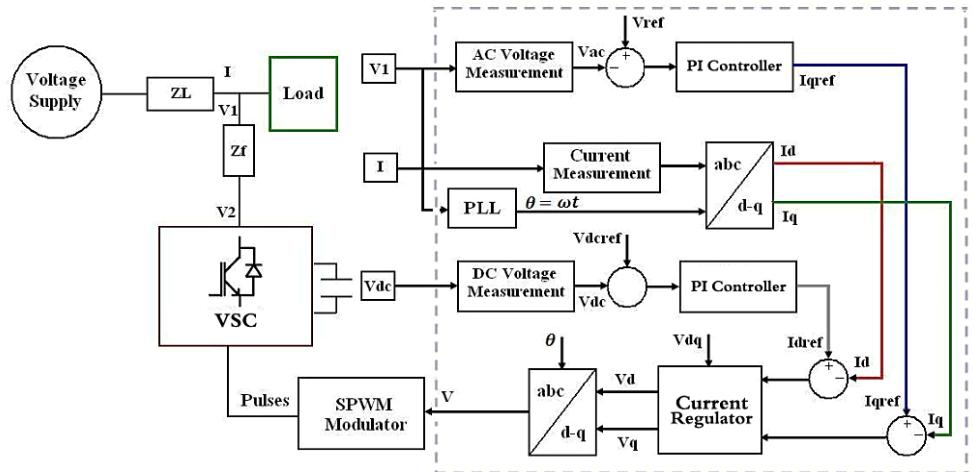


Figure 3. Control system block diagram of STATCOM

## 2.5. PI controller

PI Controller is required to control or to operate STATCOM during a disturbance in the system, such as drop in the voltage level. The voltage of Point of Common Coupling (PCC) is sensed and forwarded through a sequence analyzer. Reactive power control loop (control unit of q-coordinate) and active power control loop (control unit of d- coordinate) have a separate PI controller. As a same of feedback controllers, the PI controller operates by summing the error and integral of these values [16]. Structure of PI controller depicted in Figure 4.

The difference value between the actual and reference voltage is the input of the PI controller. For the q-coordinate control unit, the reference value for voltage is 1 p.u, where in this control, the proportional

gain ( $K_p$ ) is 5 and the integral gain ( $K_i$ ) is 1000. In the control unit of d- coordinate, the proportional gain ( $K_p$ ) and integral gain ( $K_i$ ) are 0.025. The output of the PI controller is converted into three-phase voltage and given to the SPWM pulse generator to produce the pulse and then it will be delivered to the VSC to trigger the IGBT switches.

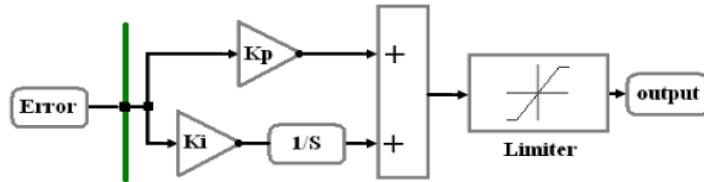


Figure 4. PI controller [10]

## 2.6. ANN controller

Neural networks have now become one of the new control technologies, it is a highly interconnected network of a great number of processing elements called neurons in a design inspired by the human brain. in generally, the body of the neural network contains several layers of neurons, an input layer, hidden layers, and an output layer [17]. As shown in Figure 5.

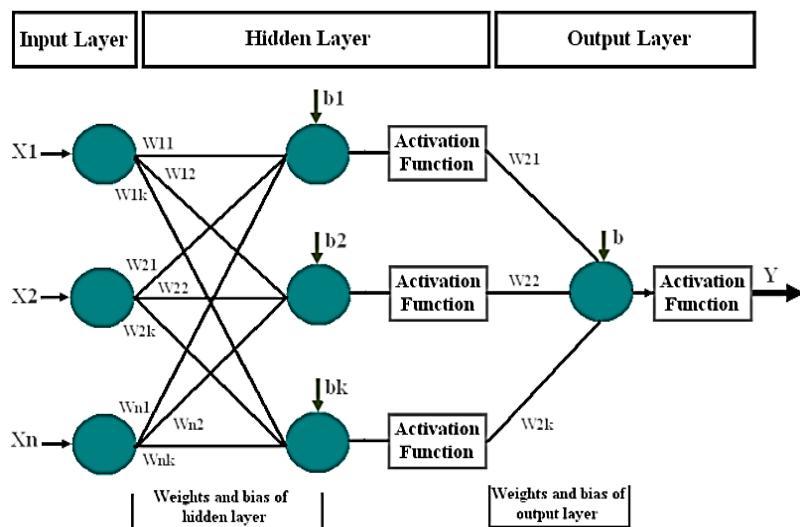


Figure 5. General structure of neural network [10]

The major object of the ANN controller is to get proper values for weights and biases which are the learnable parameters inside the controller structure that gives the required output [16].

In this research, a multilayer BP-type ANN controller was utilized to improve the performance of STATCOM. The ANN was trained by using the MATLAB toolbox; Levenberg Marquardt (LM) BP algorithm was applied as the training algorithm in this artificial neural network controller. There are three methods to find the local minimum for any given function. Gradient Descent (GD) is a first-order optimization framework, Levenberg-Marquardt Back propagation (LMBP) algorithm is a second-order optimization framework, and Gauss-Newton (GN) framework. Gradient Descent (GD) is a strong method especially when it begins far from the final minimum; meantime, it is prone to poor convergence. LM algorithm can get solutions even initiating far from the final solution. Where the LMBP method is between GD and Gauss-Newton (GN) frameworks. Levenberg-Marquardt Back propagation (LMBP) algorithm is a preferable option than to GN and GD methods [18] as it converges quickly, need low memory, and enable to learn [19].

The diagram of the ANN controller utilized in this research as shown in Figure 6, has 3 layers, consist of 1 input layer, 1 hidden layer (contained of 10 neurons), and 1 output layer. The data for training the artificial neural network are sourced from the conventional PI controller. The input of the artificial neural network is the error signal of the Vac and the error signal of the Vdc. The error is determined and a portion of it is propagated backward through the network. The ANN controller is expected to minimize this error. The performance metric of the ANN controller is the Mean square error which reflects the error between the input and the target values. 1000 epochs were required for the ANN training in the control unit of q-coordinate the best-achieved validation performance (0.00026404) was achieved at epoch 15. The number of epochs in the control unit of d- coordinate are 1000 while the best-achieved validation performance (0.00041643) is achieved at epoch 13. The ANN training was performed offline and was programmed to control the VSC STATCOM. After the offline training was completed, the next stage is to replace the conventional PI controller with the created ANN controller.

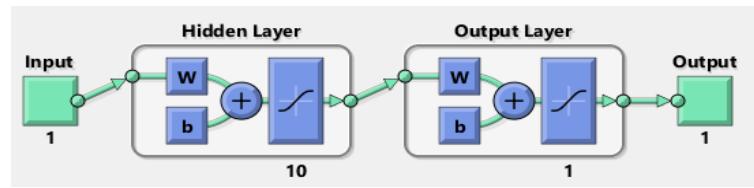


Figure 6. Diagram of neural network used in this study

### 3. MODELING OF THE TEST POWER SYSTEM

A test power system was modeled using MATLAB/Simulink software in the IEEE-14 bus. The system consists of 11 load buses, two power generators, three synchronous compensators and a total of 21 transmission lines. The test power system was designed using a phasor simulation type. The test power system operates base on a 100 MVA and base voltage of 138 KV. The design was in accordance with the IEEE-14 bus test system as shown in Figure 7. This system was used throughout all cases that were simulated.

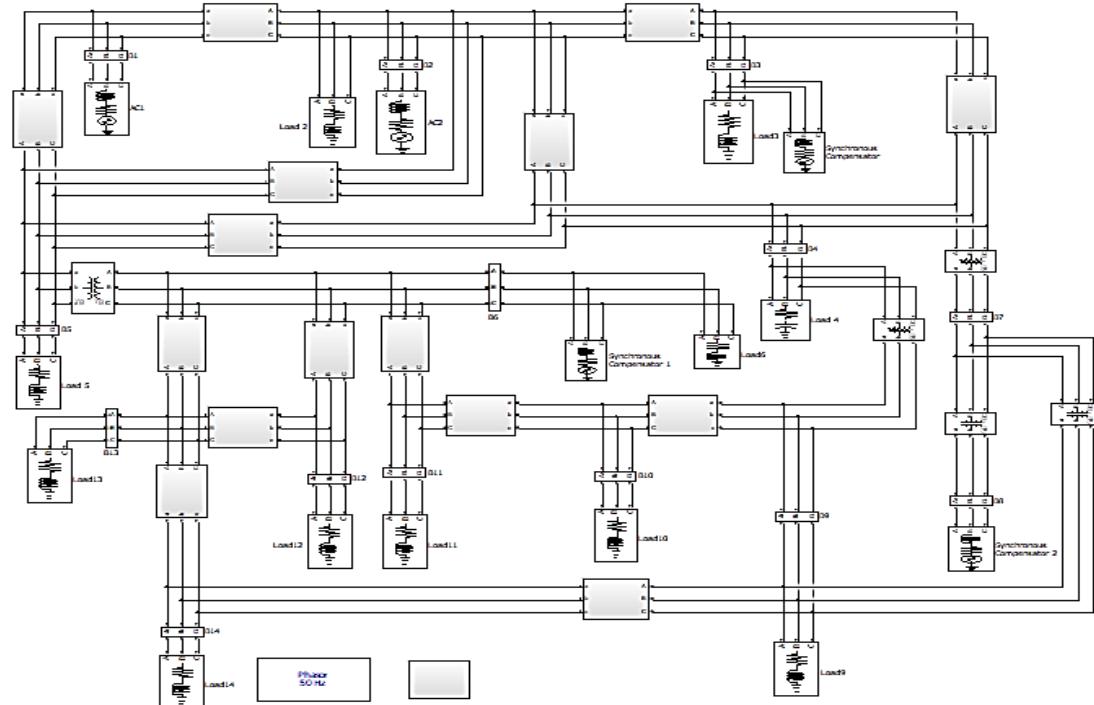


Figure 7. Model of the IEEE-14 bus system

After running the test system simulation, under the standard IEEE- 14 bus system data with no disturbance and without STATCOM. The bus voltage (p.u) result was obtained as presented in Figure 8. The result shows that the voltage at bus 1, bus7 and bus 8 has the highest voltage (p.u) at 1.057 p.u, 1.054 p.u and 1.083 p.u respectively. where these buses are not connected to any load. And by monitoring the rest of the system buses that connect to loads. It was noted that all voltages were within the permitted operating range. Where the voltage at buses 2, 3, 4, 5, 6, 9, 10, 11, 12, 13 and 14 are 1.041 p.u, 1.008 p.u, 1.011 p.u, 1.014 p.u, 1.05 p.u, 1.048 p.u, 1.043 p.u, 1.049 p.u, 1.047 p.u, 1.042 p.u and 1.026 respectively.

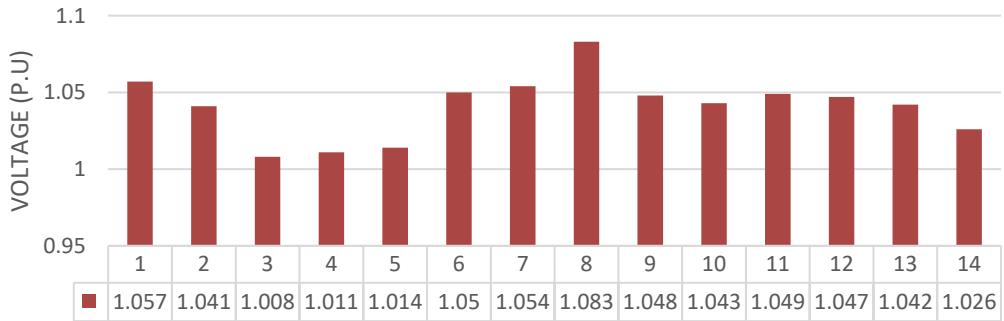


Figure 8. Voltage (p.u) for all buses at standard data

#### 4. RESULTS AND ANALYSIS OF THE TEST CASES

In this study, two cases were created to cause a disturbance in the test system, they were Load increasing case and three-phase faults case. This was done to achieve the objective of this study. For clarification, the objective was to investigate the performance of a STATCOM regard to improvement of buses voltage and damping ratio when the designed ANN controller was introduced as an alternative to the conventional PI controller in a power system. The result of using the STATCOM with PI controller was presented, then followed by the result of using the ANN in controlling the STATCOM. At every stage of implementation, the performance of the system was compared.

##### 4.1. Load increase case

In this case an increase of 300 % from the standard value of the loads were increased for all buses that connecting with a load. The justification for an increase in the load was to produce a disturbance in the test system and observe the effect on the power system to locate the weakest bus for the installation of STATCOM.

###### 4.1.1. Load increase case with out STATCOM

When the load was increased up to 300% without STATCOM the voltage associated with each bus is presented in Figure 9. By observing the results, we note the buses that connected to the generators and those close to the supply side were not affected significantly by increasing the load. Where the voltage at buses 1,2,3,6 and 8 are 1.051 p.u, 1.037 p.u, 1.004 p.u, 1.049 p.u and 1.06 p.u respectively. On the other hand, There was observe an effect on the voltage amplitude at the bus 9 (1.026 p.u), bus 10 (1.011 p.u), bus 11 (1.014 p.u), bus 12 (0.9397 p.u), bus 13 (0.9307 p.u), and bus 14 (0.8987 p.u). Therefore, buses 12, 13 and 14 were identified as the most vulnerable buses of the test cases. As the voltage of these buses is below the permitted level for operating loads. Thus, there was need to add compensation technology. Where in this study, a STATCOM device was added to the system. Previous studies had reported that the placement criterion of STATCOM is to have it connected at the weakest bus of the system [20]. The weakest bus was identified as bus 14. This is identical to the studies that have been done to identify the weakest bus on IEEE 14 BUS system [2, 6, 21, 22].

Furthermore, a comparative analysis of the effect of the increased load is presented in Table 1. It is clear from the table that the increase in load had a significant effect on the three most vulnerable buses (12, 13, and 14). Where the voltage at normal loads in these buses was 1.047 p.u, 1.042 p.u and 1.026 p.u. After the increase in the load, the voltage for the three buses was 0.93971 p.u, 0.9307 p.u and 0.8987 p.u respectively. The analysis showed that 10.25%, 10.68% and 12.41% were the voltage drop ratio in buses 12, 13 and 14 respectively. This decrease in voltage due to the site of these buses far from the power sources

(generators) [21], where the system cannot meet the required of reactive power due to the increased load, and if this reactive power does not compensate it will lead to voltage instability or even voltage collapse [23].

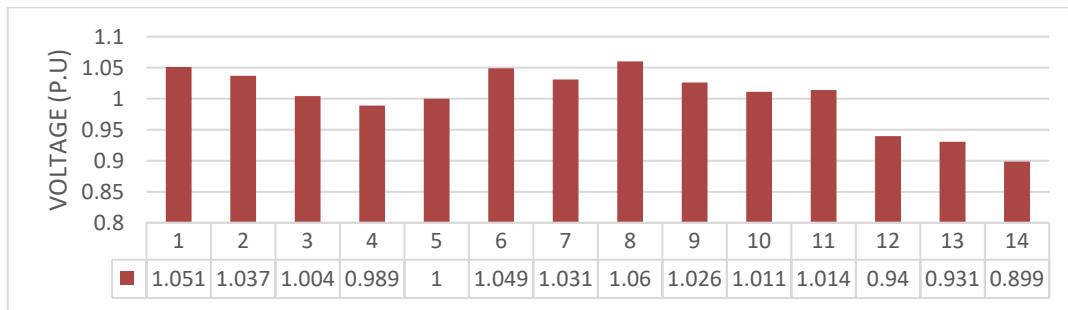


Figure 9. Voltage (p.u) for all buses at load increase case without STATCOM)

Table 1. Voltage drop at buses 12, 13 and 14 between normal and load increase case.

Buses	Voltage when normal case (p.u)	Voltage when load increase case (p.u)	Voltage drop (%)
12	1.047	0.9397	10.25%
13	1.042	0.9307	10.68%
14	1.026	0.8987	12.41%

#### 4.1.2. Load increase case with STATCOM

In this section, STATCOM will be introduced to the test system, to improve the result obtained in the load increase case. A significant decrease in voltage was observed on buses 12, 13 and 14. It will focus on these three buses and explain the effectiveness of the STATCOM to improve the voltage level. From the previous case, a suitable place to connect the STATCOM to the system was determined on bus 14. The effect of a conventional PI controlled STATCOM and that of ANN controlled STATCOM are presented. The aim was to compare the efficiency of the PI and ANN controllers [24, 25]

##### a. STATCOM based on a conventional PI controller

In this case, the STATCOM was used with conventional PI control to mitigate the voltage weakness and the results were as displayed in Figure 10. The buses connected to generation sources are still at about the same value. bus 1 (1.05 p.u) bus 2 (1.037 p.u) , bus 3 (1.003 p.u), bus 6 (1.05 p.u) and bus 8 (1.055 p.u). While the voltage on buses 4,5,7,9,10,11 is 0.986 p.u ,1.001 p.u, 1.027 p.u, 1.021 p.u, 1.008 p.u and 1.012 p.u respectively.

With particular interest to the weakest buses, STATCOM with the PI controller had an effect on improve voltage level, where bus 12 had a voltage amplitude of 0.955 p.u, while 13 and 14 had 0.96 p.u and 0.972 p.u respectively. As displayed in the following Figure 11.

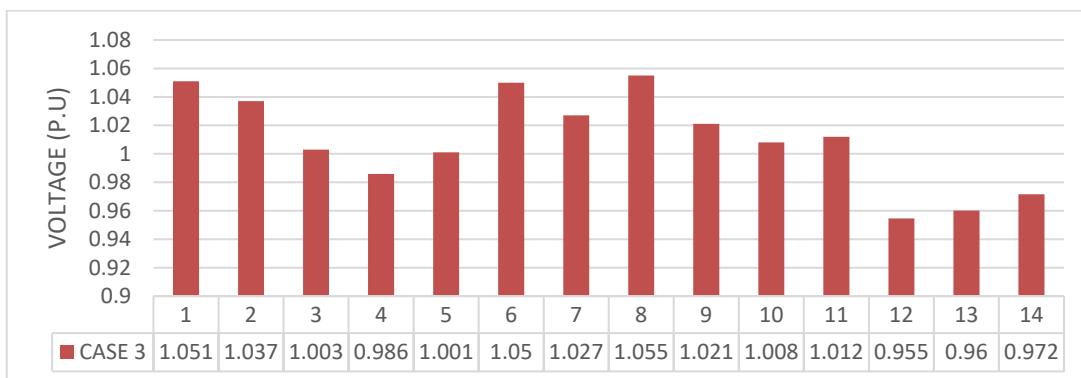


Figure 10. Voltage (p.u) for all buses at (load increase case use StatCom with PI controller)

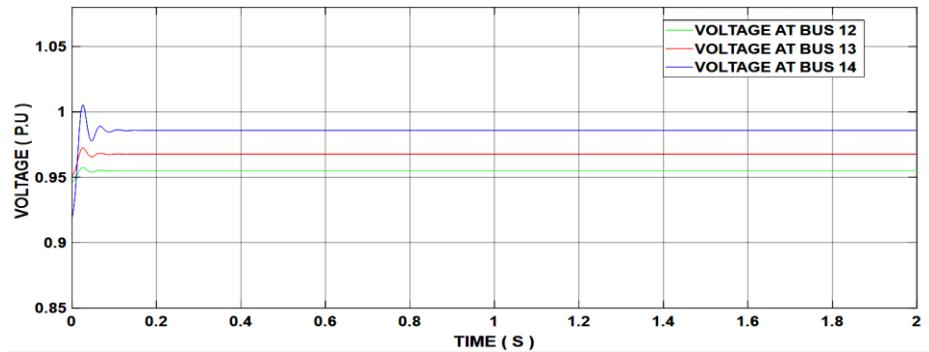


Figure 11. Voltage at B12, B13, B14, (load increase case use StatCom with PI controller)

b. STATCOM based on an ANN controller

The PI controller has been replaced with the designed ANN controller in the control circuit of the STATCOM. This was in furtherance to the objective of this study, which is to compare the performance of the PI-controlled STATCOM with the ANN-controlled STATCOM [26, 27]. For clarifications, the function of the ANN was to deliver a swift and dynamic response and improve the stability of the system for a large operating range. The result obtained is presented in Figure 12. It is clear from the results; the ANN was able to provide more stability to the power system as it improved the voltage level on the weak buses that were connected to STATCOM. On the other hand, there is no change was observed in the rest of the buses which far from the STATCOM connection point.

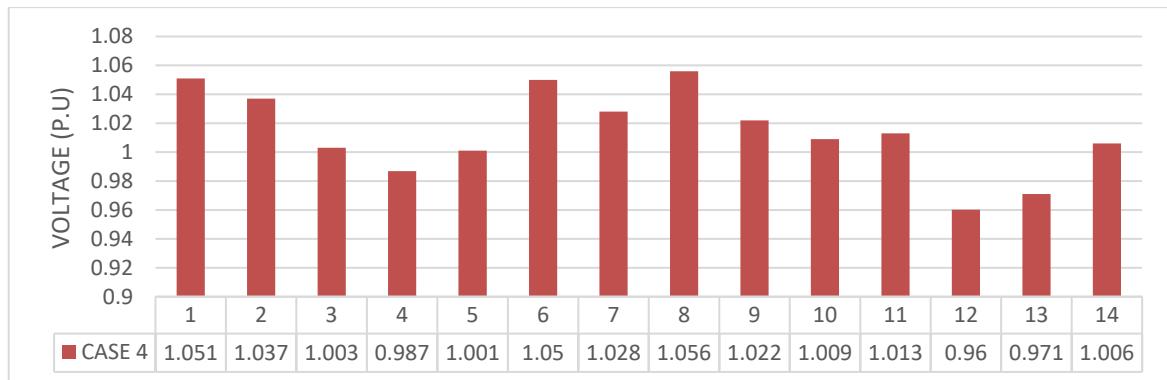


Figure 12. Voltage (p.u) for all buses at (load increase case use StatCom with PI controller)

Figure 13 shows the effect of ANN on weak buses, as the level of voltage at buses 12, 13 and 14 is 0.9602 p.u, 0.971 p.u and 1.006 p.u, respectively. And also, the damping time is better than use PI controller.

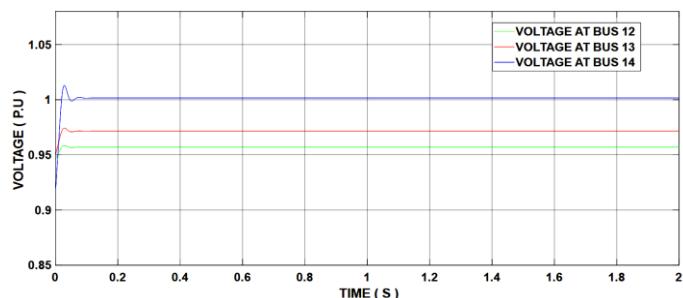


Figure 13. Voltage at B12, B13, B14, (load increase case use StatCom with ANN controller)

#### 4.1.3. Performance comparison of ANN controller against PI controller during load increase case.

To achieve a comparison between the performance of the two controllers(PI and ANN) during the load increasing case, from the results shown in the figure10,11 and 13. It should be noted that the weakest buses during this case bus 12, 13 and 14, were the most affected by the addition of STATCOM. Tables 2 and 3 show the rate of improvement for both controllers on these buses.

Table 2. Voltage improvement rate when use StatCom with PI controller

Buses	Voltage when load increase case (p.u)	Voltage when statcom with pi (p.u)	Voltage improvement (%)	Damping time (s)
12	0.9397	0.9546	1.59%	
13	0.9307	0.9601	3.16%	0.09
14	0.8987	0.9716	8.11%	

Table 3. Voltage improvement rate when use StatCom with ANN controller

Buses	Voltage when load increase case (p.u)	Voltage when statcom with ann	Voltage improvement (%)	Damping time (s)
12	0.9397	0.9602	2.18%	
13	0.9307	0.9710	4.33%	0.05
14	0.8987	1.006	11.94%	

It is clear from the result in Table 2 that when the load was increased in bus 12, the voltage was 0.9397 p.u .however, when the implementation of STATCOM with the PI controller, the voltage level improved to 0.9602 p.u. Also, when this result was compared with the initial case of increased load, an improvement of 2.18 % was observed. The result got better in subsequent buses herein reported with 4.33% and 11.94% improvements obtained in buses 13 and 14 respectively. A comparison of the result in the three buses as presented in Table 3 showed a better and more improved performance of the STATCOM when the ANN was used as a controller [28]. Here, the improvement obtained was 2.18% %, 4.33% % and 11.94% % in bus 12, 13, and 14 respectively. The damping time was also reduced from 0.09 s when using PI to 0.05 s when ANN controlled STATCOM. It should be noted that a great improvement was obtained in the weakest bus 14 where the STATCOM was placed [29]. For instance, the voltage level in the respective buses was 0.9602 p.u, 0.9710 p.u and 1.006 p.u when ANN was used as against the 0.9397 p.u, 0.9307 p.u and 0.8987 p.u obtained when the load was increased without STATCOM. Figure 14 shows the comparison of buses 12,13 and 14 for load increase cases. And a comprehensive comparison of the result in all the load increase cases is presented in Figure 15.

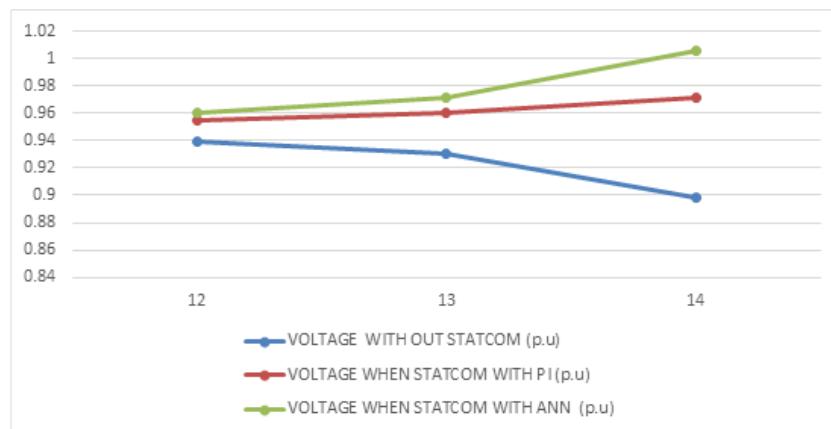


Figure 14. Comparison of buses 12,13 and 14 for load increase cases

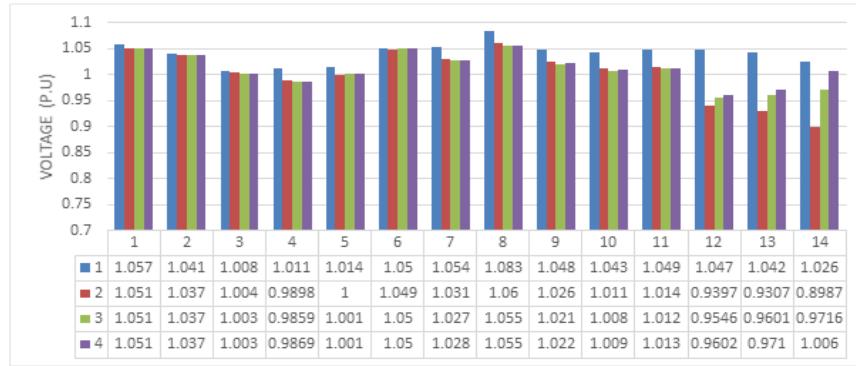


Figure 15. Comprehensive comparison of the result in all the load increase cases

#### 4.2. Three-phase fault case

In this case, the effectiveness of using the STATCOM was tested in the case that the system was occurred to a three-phase fault at bus-3 during a period from 1 to 1.5 seconds. As known, the three-phase fault is the greatest fault that occurs in the system. The results were compared with two controllers (PI/ANN) to mitigating voltage drop which occurred at bus3.

A three-phase fault has been applied at bus 3, the first simulation was performed without using STATCOM; it can be observed that the voltage drops at bus 3 was 0.851 p.u (15.58% of the reference voltage (1.008 p.u)) as displayed in Figure 16.

The second simulation was carried out using STATCOM based on a conventional PI controller connected to the IEEE 14-bus system at bus-3 during three-phase fault, the STATCOM generated the reactive power to the system; then, the voltage sag was mitigated, and the PI took 0.072 sec to maintain voltage at the bus-3 to 0.953 p.u (percentage of improvement 11.98 %) as shown in Figure 17.

Figure 18. explained the last simulation that was performed with STATCOM based on ANN controller. In this simulation, ANN needed 0.023 sec to improve the voltage to 0.978 p.u (percentage of improvement 14.92%) because the ANN controller reduced the errors to the minimum value.

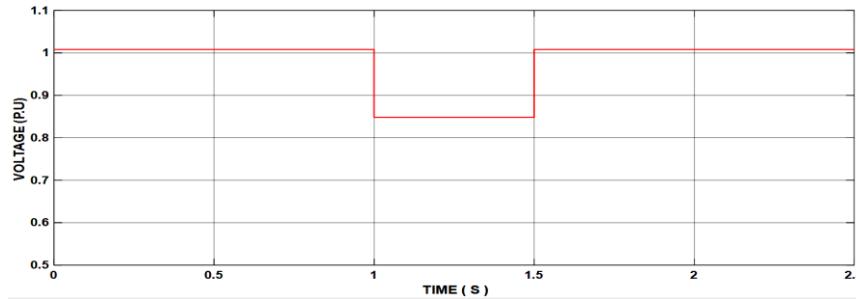


Figure 16. Voltage at bus-3 during three-phase fault period without STATCOM

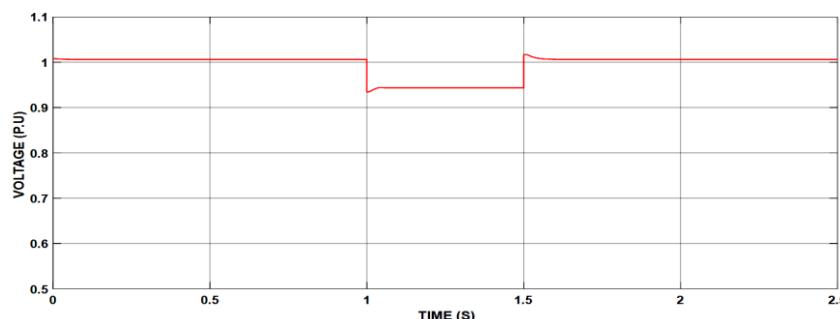


Figure 17. Voltage at bus-3 during three-phase fault period with STATCOM based on PI

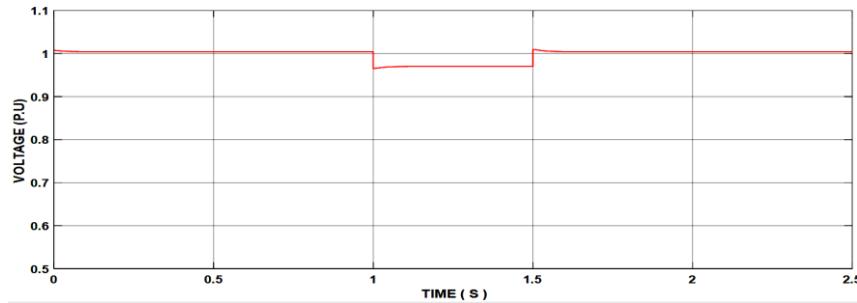


Figure 18. Voltage at bus-3 during three-phase fault period with STATCOM based on ANN.

#### 4.2.1. Performance comparison of ANN controller against PI controller during three-phase fault

To achieve the aim of this study. The performance of the STATCOM was compared when using the two controllers (PI / ANN) during the three-stage fault period on bus 3. After simulation it was apparent that the designed ANN unit gives better results compared to the conventional PI control unit. The comparison of the performance, response time, and rate of Improvement between PI and ANN illustrated in table 4.

Table 4. Comparison of the performance during the three-phase fault period at bus 3.

Comparison Parameter	PI controller	ANN controller
Voltage during fault period (p.u)	0.953	0.978
Response Time (sec)	0.072	0.023
Improvement ratio (%)	11.98	14.92

## 5. CONCLUSION

In this paper, an ANN controller was designed and proposed as an Intelligent control method instead of the conventional PI controller to provide a suitable control signal to improve the characteristics and performance of STATCOM in power system. An IEEE-14 bus power system has been simulated in MATLAB environment to evaluate the STATCOM performance with PI and ANN controller during cases of load increase and three-phase fault. The simulation results revealed that the STATCOM-based intelligent control methodology (ANN), provided better features as we obtained an improvement on power stability and fast dynamic response time during the two test cases in comparison to the conventional PI-based STATCOM.

## REFERENCES

- [1] N. Ismail and W. N. W. Abdullah, "Enhancement of power quality in distribution system using D-STATCOM," in *2010 4th International Power Engineering and Optimization Conference (PEOCO)*, 2010: IEEE, pp. 418-423.
- [2] A. Anbarasan and M. Sanavullah, "Voltage stability improvement in power system by using statcom," *Int J Eng Sci Technol*, vol. 4, no. 11, 2012.
- [3] B. K. Jadon, "Transient Stability Improvement of IEEE 14 Bus System with STATCOM," *International Journal of Innovative Science and Research Technology*, vol. 2, no. 7, 2017.
- [4] N. Rana and S. Aggarwal, "Reactive Power Compensation using STATCOM," *International Journal of Computer Applications*, vol. 975, p. 8887, 2015.
- [5] Y. Ma, A. Huang, and X. Zhou, "A review of STATCOM on the electric power system," in *2015 IEEE International Conference on Mechatronics and Automation (ICMA)*, IEEE, pp. 162-167, 2015.
- [6] I. Alhamrouni, R. Ismail, M. Salem, B. Ismail, A. Jusoh, and T. Sutikno, "Integration of STATCOM and ESS for power system stability improvement," *International Journal of Power Electronics and Drive Systems (IJPEDS)*, vol. 11 No. 2, pp. 868-878, 2020.
- [7] S. U. Shinde, M. Sharmila, R. S. Patil, and D. V. Makhede, "Performance comparison of PI & ANN based STATCOM for 132 KV transmission line," in *2016 International Conference on Electrical, Electronics, and Optimization Techniques (ICEEOT)*, 2016: IEEE, pp. 2730-2734.
- [8] S. F. S. J. Raglend, "A review on pi control of statcom for voltage regulation," *Chemical and Pharmaceutical Sciences*, vol. 9, pp. 334-340, 2016.
- [9] Y. Xu and F. Li, "Adaptive PI control of STATCOM for voltage regulation," *IEEE transactions on power delivery*, vol. 29, no. 3, pp. 1002-1011, 2014.
- [10] M. M. Almelian *et al.*, "Enhancing the performance of cascaded three-level VSC STATCOM by ANN controller with SVPWM integration," *International Journal of Electrical & Computer Engineering*, vol. 9, No. 5, pp. 3880-3890, 2019.

[11] C. V. R. S. Dattabhimaraju.P, "ANN Controlled STATCOM for Improving Transient Stability of the Power System," *International Journal of Engineering Research & Technology (IJERT)*, vol. Vol. 2, no. 2, February- 2013.

[12] D. I. J. R. S. Felix Stephen "Voltage Regulation Using STATCOM with PI and Adaptive PI Controls," *International Journal of Engineering & Technology*, vol. 7, pp. 178-182, 2018.

[13] D. Shen and P. Lehn, "Modeling, analysis, and control of a current source inverter-based STATCOM," *IEEE Transactions on power delivery*, vol. 17, no. 1, pp. 248-253, 2002.

[14] Y. A. M. Nasiru B. Kadandani "Simulation of Static Synchronous Compensator (STATCOM) for Voltage Profile Improvement," *Innovative Systems Design and Engineering*, vol. Vol.6, No.7, pp. 2222-2871, 2015.

[15] A. Augustine, E. Paul, R. D. Prakash, B. M. Balakrishna, and R. Xavier, "Voltage regulation of STATCOM using fuzzy self tuning PI controller," in *2016 International Conference on Circuit, Power and Computing Technologies (ICCPCT)*, 2016: IEEE, pp. 1-7.

[16] C. Sundarabalan and K. Selvi, "Power quality enhancement in power distribution system using artificial intelligence based dynamic voltage restorer," *International Journal on Electrical Engineering and Informatics*, vol. 5, no. 4, p. 433, 2013.

[17] S. Messalti, B. Boudjellal, and A. Said, "Artificial neural networks controller for power system voltage improvement," in *IREC2015 The Sixth International Renewable Energy Congress*, IEEE, pp. 1-6, 2015.

[18] S. Sugasini, M. Y. Mashor, N. A. M. Isa, and N. H. Othman, "Performance comparison for MLP networks using various back propagation algorithms for breast cancer diagnosis," in *International Conference on Knowledge-Based and Intelligent Information and Engineering Systems*, Springer, pp. 123-130, 2005.

[19] N. I. A. Wahab, B. Ismail, L. J. Awalin, I. Alhamrouni, N. S. M. Shaberon, and M. M. Naain, "Voltage Stability Indices Studies on Optimal Location of Wind Farm in Distribution Network," *2017 IEEE Conference on Energy Conversion (CENCON)*, pp. 111-116, 2017.

[20] H. A. Hassan, Z. H. Osman, and A. E.-A. Lasheen, "Sizing of STATCOM to enhance voltage stability of power systems for normal and contingency cases," *Smart Grid and Renewable Energy*, vol. 2014, 2014.

[21] F. Mahmood *et al.*, "Weakest location exploration in IEEE-14 bus system for voltage stability improvement using STATCOM, synchronous condenser and static capacitor," in *2017 International Conference on Electrical, Computer and Communication Engineering (ECCE)*, 2017: IEEE, pp. 623-629.

[22] S. Dey and S. Ghatak, "Performance Improvement of Power System using STATCOM by Considering Weak Zone of the Network," in *2019 IEEE International Conference on Sustainable Energy Technologies (ICSET)*: IEEE, pp. 247-250.

[23] R. C. Lu's Rocha, "Optimal Placement of STATCOM for Voltage Stability Enhancement using Particle Swarm Optimization," 2018.

[24] L. Tey, P. So, and Y. Chu, "Neural network-controlled unified power quality conditioner for system harmonics compensation," in *IEEE/PES Transmission and Distribution Conference and Exhibition*, 2002, vol. 2: IEEE, pp. 1038-1043.

[25] I. Alhamrouni, M. Alif, B. Ismail, M. Salem, A. Jusoh, and T. Sutikno, "Load Flow Based Voltage Stability Indices for Voltage Stability and Contingency Analysis for Optimal Location of STATCOM in Distribution Network with Integrated Distributed Generation Unit," *TELKOMNIKA Telecommunication, Computing, Electronics and Control*, vol. 16, no. 5, pp. 2302- 2315 2018.

[26] F. M. Albatsh, S. Mekhilef, I. Alhamrouni, S. Ahmad, and M. A. Hamid, "Power Flow Control using Fuzzy Based UPFC under different operating conditions," *Journal of Electrical Systems*, Vol. 13, No. 2, pp. 398-414, 2017.

[27] B. Ismail *et al.*, "Short circuit current and voltage sag profile studies for optimal location of DG in distribution network," in *AIP Conference Proceedings*, 2019, vol. 2129, no. 1: AIP Publishing LLC, p. 020136.

[28] M. M. Almelian *et al.*, "Enhancement of cascaded multi-level VSC STATCOM performance using ANN in the presence of faults," *International Journal of Power Electronics and Drive Systems (IJPEDS)*, vol. 11, no. 2, pp. 895-906, 2020.

[29] B. Ismail, M. M. Naain, N. I. A. Wahab, L. J. Awalin, I. Alhamrouni, and M. F. A. Rahim, "Optimal placement of DSTATCOM in distribution network based on load flow and voltage stability indices studies," in *2017 International Conference on Engineering Technology and Technopreneurship (ICE2T)*, 2017: IEEE, pp. 1-6.